The Story of Phosphorus

Sustainability implications of global phosphorus scarcity for food security

PhD thesis

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This thesis is the product of a *cotutelle* agreement (collaborative doctoral degree) between the following two institutions:

Institute for Sustainable Futures, University of Technology, Sydney
(PhD in Sustainable Futures)

and

Department of Water and Environmental Studies, Linköping University
(PhD in Water and Environmental Studies)

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree and nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and in the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Student

_____

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When I told people I was undertaking a joint PhD literally between Australia and Sweden, they tended to visualize an exotic life of a young researcher networking the globe and chasing endless summers between Sydney's sunny beaches and Sweden's idyllic forests bursting with wild blueberries and *kantareller* mushrooms. While that image was relatively true, there was the less exotic side of physically shifting an office worth of literature and ideas back and forth across the globe; of never fitting into bureaucratic boxes of the universities, immigration board or insurance companies; of continually packing and unpacking apartments, of missing the births, weddings and birthdays of friends and family; not to mention the guilt of clocking up thousands of CO_2 miles, all in the name of 'sustainability' research.

Finding the motivation to work day and night for 3½ years was rarely a challenge in this doctoral journey. The topic was enthralling and the research exhilarating to me at (almost) all times. Even frequent face-to-face supervisor meetings across time zones that differed by eight hours were quite straightforward thanks to *skype* and *iCHAT* and inbuilt laptop cameras. The real challenges were: firstly, commencing research on a problem situation that many scientists and policy-makers dismissed because they believed 'the market would take care of it'; secondly, taking to the scientific investigation a non-conventional transdisciplinary approach that responded to the changing situation rather than adhering to a single, traditional disciplinary boundary; and finally, navigating a PhD between not just two countries, but two very different university institutions with different values, structures and approaches.

What made this challenging PhD possible and indeed, what made this thesis what it is, were the numerous mentors I gained as I travelled across the globe. Mentors come in all shapes and sizes, from supervisors and colleagues, to friends and family to strangers sitting next to you on long-haul flights from Sydney to Stockholm. This web of mentors knew what tricky or reflective questions to ask, and supported my transdisciplinary approach and research when others were dismissing it as unconventional. Through my doctoral travels, there's been an unbelievable growing network of mentors, friends, colleagues and administrators who have supported my research in many many ways (hence the length of this 'Acknowledgements' section).

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PAPERS

This thesis is based on the following five papers, which will be referred to in the text by their Roman numerals:

Paper I:

Cordell, D., Drangert, J.-O., and White, S., (2009), *The story of phosphorus: Global food security and food for thought*. **Global Environmental Change**, 2009. 19(2009) p. 292-305.

Paper II:

Cordell, D. (2008), *Phosphorus, food and 'messy' problems: A systemic inquiry into the management of a critical global resource*, ANZSYS 2008, Edith Cowan University, December 2008 in Proceedings of the 14th **ANZSYS Australia New Zealand Systems Society Conference**, ed David Cook, SECAU - Security Research Centre, Edith Cowan University, Perth, pp. 1-15. ISBN 978-0-7298-0668-8. (Reprinted with permission from Edith Cowan University and ANZSYS 2008 Conference Committee).

Paper III:

Cordell, D. (submitted), *Phosphorus: A nutrient with no home – multiple stakeholder perspectives on a critical global resource for food security* (Submitted for publication).

Paper IV:

Cordell, D., Neset, T. S. S., Drangert, J.-O. & White, S. (2009), *Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand*, International Conference on Nutrient Recovery from Wastewater Streams, Vancouver, 2009. Edited by Don Mavinic, Ken Ashley and Fred Koch. ISBN: 9781843392323. Published by **IWA Publishing**, London, UK. (p.23-44 reprinted with permission from the copyright holders, IWA Publishing).

Paper V

Cordell, D. & White, S. (submitted), *The Australian story of phosphorus: Implications of global phosphate scarcity for a nation built on the sheep's back* (Submitted for publication).

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LIST OF ABBREVIATIONS

CEEP	*Centre Européen d'Etudes sur les Polyphosphates (representing the European industrial/cleaning sector of the phosphate industry)*
CGIAR	*Consultative Group on International Agricultural Research*
CSIRO	*Commonwealth Scientific and Industrial Research Organization (Australia)*
CST	*Critical systems thinking*
CRU	*British Sulphur Consultants*
DAP	*Diammonium phosphate*
ESG	*Earth System Governance project*
ESSP	*Earth System Science Partnership*
FAO	*Food and Agricultural Organization of the United Nations*
FAOSTATS	*Online statistical database of the FAO*
FIFA	*Fertilizer Industry Federation of Australia*
GEC	*Global environmental change*
GECAFS	*Global Environmental Change and Food Systems program*
GPRI	*Global Phosphorus Research Initiative*
IAASTD	*International Assessment of Agricultural Knowledge, Science and Technology for Development*
IDGEC	*Institutional Dimensions of Global Environmental Change*
IFA	*International Fertilizer Industry Association*
IFADATA	*Online statistical database of the IFA*
iFOAM	*International Federation of Organic Agriculture Movements*
IFPRI	*International Food Policy Research Institute*
IMPHOS	*The World Phosphate Institute*
K	*Potassium*
MAP[1]	*Monoammonium phosphate*
MDG	*Millennium Development Goals*
MT	*Million metric tonnes*
N	*Nitrogen*
OCP	*Office Cherifien de Phosphate (Morocco's phosphate company)*
P	*Phosphorus*
SEI	*Stockholm Environment Institute*
SFA	*Substance Flows Analysis*
SSM	*Soft systems methodology*
TSP	*Triple Superphosphate*
UDHR	*Universal Declaration on Human Rights*
UN	*United Nations*
USGS	*US Geological Survey*
WHO	*World Health Organization of the United Nations*
WTO	*World Trade Organization*

[1] Struvite is also referred to as MAP (magnesium-ammonium-phosphate), however to avoid ambiguity, the common name struvite has been used.

ABSTRACT

The story of phosphorus began with the search for the philosopher's stone, and centuries later the critical role of phosphorus in soil fertility and crop growth was highlighted. Eventually, phosphorus was implicated in the global environmental challenge of eutrophication. Now, we are on the brink of yet another emerging chapter in the story: global phosphorus scarcity linked to food security. Through a transdisciplinary and systemic inquiry, this thesis has analyzed, reconceptualized and synthesized the physical and institutional dimensions of global phosphorus scarcity in the context of food security, leading to a new framing, 'phosphorus security' to guide future work towards a more sustainable and food secure pathway.

In a world which will be home to nine billion people by the middle of this century, producing enough food and other vital resources is likely to be a substantial challenge for humanity. Phosphorus, together with nitrogen and potassium, is an essential plant nutrient. It is applied to agricultural soils in fertilizers to maintain high crop yields. Phosphorus has no substitute in food production. Therefore, securing the long-term availability and accessibility of phosphorus is crucial to global food security. However the major source of phosphorus today, phosphate rock, is a non-renewable resource and high quality reserves are becoming increasingly scarce. This thesis estimates peak phosphorus to occur before 2035, after which demand will exceed supply. Phosphorus scarcity is defined by more than just *physical* scarcity of phosphate rock and this thesis develops five important dimensions. For example, there is a scarcity of *management* of phosphorus throughout the entire food production and consumption system: the global phosphorus flows analysis found that only 20% of phosphorus in phosphate rock mined for food production actually reaches the food consumed by the global population due to substantial inefficiencies and losses from mine to field to fork. There is also an *economic* scarcity, where for example, while all the world's farmers need access to sufficient fertilizers, only those with sufficient purchasing power can access fertilizer markets. *Institutional* scarcity, such as the lack of governance structures at the international level that explicitly aim to ensure long-term availability of and access to global phosphorus resources for food production that has led to ineffective and fragmented governance of phosphorus, including a lack of: overall coordination, monitoring and feedback, clear roles and responsibilities, long-term planning and equitable distribution. Finally, *geopolitical* scarcity arising from 90% of the world's remaining high-grade phosphate rock reserves being controlled by just five countries (a majority of which are subject to geopolitical tensions) can limit the availability of phosphorus on the market and raises serious ethical questions.

The long-term future scenarios presented in this thesis indicate that meeting future global food demand will likely require a substantial reduction in the global demand for phosphorus through not only improved efficient use of phosphorus in agriculture, but also through changing diets and increasing efficiency in the food chain. The unavoidable demand for phosphorus could then be met through a high recovery and reuse rate of all sources of phosphorus (crop residues, food waste, manure, excreta) and other sources including some phosphate rock. A 'hard-landing' situation could involve further fertilizer price spikes, increased waste and pollution (including eutrophication), increased energy consumption associated with the production and trade of phosphorus fertilizers, reduced farmer access to phosphorus, reduced global crop yields and increased food insecurity. A preferred 'soft landing' situation will however require substantial changes to physical and institutional infrastructure, including improved governance structures at the global, national and other levels, such as new policies, partnerships and roles to bring together the food, fertilizer, agriculture, sanitation and waste sectors for a coordinated response.

Finally, this thesis proposes a new global goal – *phosphorus security* – to be integrated in the dominant research discourses and policy debates on global food security and global environmental change. Among other criteria, phosphorus security requires that phosphorus use is decoupled from environmental degradation and that farmers' access to phosphorus is secured.

Keywords: *global phosphorus scarcity, peak phosphorus, global food security, sustainable resource use, food production and consumption system, transdisciplinary, systems thinking.*